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NASA LCLUC Program
An Integrated Forest Monitoring System for Central Africa



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Abstract

Central Africa has the second largest unfragemented block of tropical rain forest in the world; it is also one of the largest carbon and biodiversity reservoirs. With nearly one-third of the forest currently allocated for logging, the region is poised to undergo extensive land-use change. Through the mapping of the forests, our Integrated Forest Monitoring System for Central Africa (INFORMS) project aims to monitor habitat alteration, support biodiversity conservation, and promote better land-use planning and forest management. Designed as an interdisciplinary project, its goal is to integrate data acquired from satellites with field observations from forest inventories, wildlife surveys, and socio-economic studies to map and monitor forest resources. This project also emphasizes on collaboration and coordination with international, regional, national, and local partners--including non-profit, governmental, and commercial sectors. This project has been focused on developing remote sensing products for the needs of forest conservation and management, insuring that research findings are incorporated in forest management plans at the national level.

The societal impact of INFORMS can be also appreciated through the development of a regional remote sensing network in central Africa. With a regional office in Kinshasa, (www.OSFAC.org), the contribution to the developemnt of forest management plans for 1. 5 million hectares of forests in northern Republic of Congo (www.tt-timber.com), and the monitoring of park encroachments in the Albertine region (Uganda and DRC) (www.albertinerift.org).

Key words:
Research Fields: Habitat Conversion, Deforestation, Vegetation Mapping
Geographic Area/Biome: Central Africa, Tropical Forest
Remote Sensing: Radar, MODIS, IKONOS, LANDSAT, digital video surveys
Methods/scales: Local to Regional Scale, Data Fusion, Change detection

Mapping and Monitoring Central African Rainforest
Remote sensing research and applications (75%), Social science (25%)
Carbon (25%), GOFC (50%), Biodiversity Monitoring (25%)

Central African forests are one of the largest carbon reservoirs on Earth but relatively little is known about the impact of agriculture and logging on carbon stocks in this region. Changes in forest biomass under different land-use scenarios have been addressed in other tropical forest regions (e.g., the Amazon Basin), but the modes of forest harvest and use are very different in Africa. Levels of forest fragmentation and the intensity of forest biomass removal is still largely unknown or poorly documented. As part of INFORMS we developed a strategy to address these needs, and made progress on implementing them, as summarized below.

Goals / Science implication

- Better characterisation of tropical forest land surfaces and processes.
- Develop multi-scale multi-sensor data integration methods and appropriate validation tools.
- Develop operational monitoring systems to support environmental policies

- Integration of central African research scentists in regional science activities (eg GOFC-OSFAC).

Approach / Methods

Develop new forest monitoring approaches under the framework of Global Observations of Forest Cover (GOFC), including:

- Development of methodologies to assess and map central Africa forests and rates of deforestation using multi-sensor, multi-scale satellite observations, providing improved vegetation maps for applications at the local and regional scale.
- Development of forest monitoring techniques integrating new remote sensing information, biodiversity and forestry information in collaboration with international organizations and local stakeholders to facilitate forest conservation.

In this brief final report we will focus on our achievements. More details on approaches and methods can be found at www.whrc.org/africa.

Achievements / Results

Characterization and mapping of land cover/land use in Central African rainforest is complex. This complexity is exacerbated by (1) the diversity of human land uses and (2) the lack of full and continuous cloud-free coverage by any single remote sensing instrument. In order to provide improved vegetation maps of Central Africa and to develop forest monitoring techniques for applications at the local and regional scales, and develop remote sensing capacity we have focused on:

A. Developing operational land-use monitoring systems
B. Developing methods for land-cover mapping for forest conservation
C. Assessing the use of Radar imagery for biomass mapping and data fusion
D. Developing a remote sensing network as part of the GOFC initiative

A. Developing an operational land-use change monitoring system

Selective logging is the most prevalent land use in the Congo Basin (30% of the forest) and more timber companies are expected to begin operations in the coming year (see figure 1). Although historically logging intensity is relatively low in most of Central Africa compared to Southeast Asia and the Brazilian Amazon, harvesting volumes are steadily increasing. Even long established timber companies are exploring secondary species as parts of the forest are exhausted of primary timber species. Over-harvesting of timber is rarely monitored or controlled, and long-term forest ecosystem, community, and population responses to this high-grading process are largely understudied. Furthermore, logging roads create access to commercial hunters and poachers into previously remote areas of the forest, and migration into logging towns causes increasing rates of deforestation.

The NASA-INFORMS project produced crucial information for the forest management of northern Republic of Congo. These results include 1) monitoring the increase of logging roads in northern Congo ;) assessment of deforestation rates around major population centers (logging towns), and 3) the development of a forest logging intensity index

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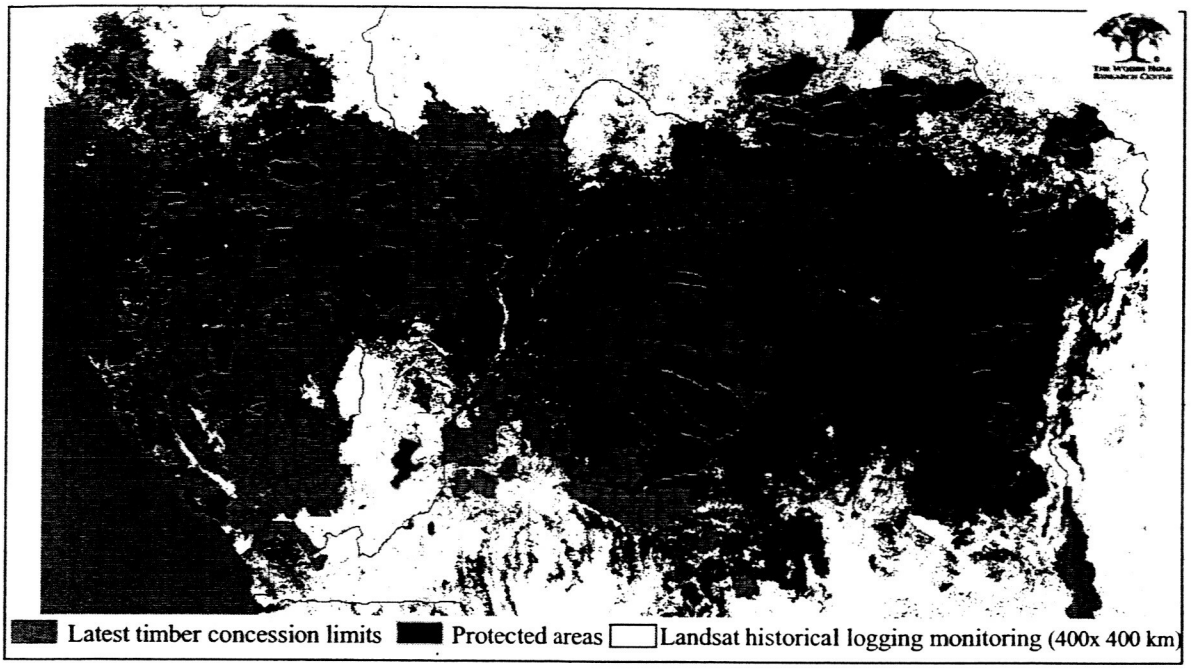

Figure 1. Distribution of timber concessions and protected areas in Central Africa.

A-1. Mapping logging history using Landsat (1970 - 2002)

In the northern Republic of Congo alone, the total length of logging roads established in the last 30 years was estimated to be more than 6,000 km, or two times the total length of primary roads in the entire country (Figure 2). This equates to an eleven-fold increase in the last 25 years. Similar rates of logging expansion are anticipated in D.R.C. when the political situation is stabilized.

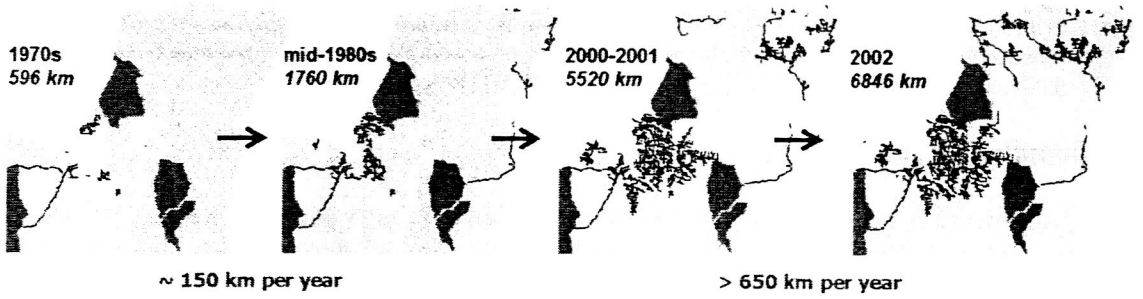

Figure 2. Historical logging monitoring in Northern Congo: mapping roads from Landsat images of 1970s-2000s.

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Laporte, N.T., and T.S. Lin. 2003. *Monitoring logging in the tropical forest of Republic of Congo with Landsat imagery*, International Geoscience and Remote Sensing Symposium (IGARSS), July 2003 Toulouse, Ref # 8.1812- INT-A17. http://www.igarss03.com/

Laporte, N., T.S. Lin, and D. Devers. 2003. *Impacts of Large-Scale Selective Logging on Ecosystem Services in the Northern Republic of Congo*, AGU Chapman Conference Ecosystem Interactions with Land Use Change 14-18, June 2003 Santa Fe, New Mexico.

A-2. Assessing rates of deforestation in logging towns

Northern Republic of Congo is an important area to develop an understanding of the impact of logging on central African forests. Logging is the dominant land use for most of this otherwise largely undisturbed natural region (and National Park). Current rates of deforestation associated with logging in the region are poorly documented. Our mapping of land-use change associated with logging at Pokola shows that logging towns have a higher rate of deforestation compared to non-logging towns (Ouesso). In logging towns new fields are cleared in forests, whereas in non-logging towns clearing takes place primarily in fallow areas which are easier to clear and more accessible. Urbanization is also progessing rapidly in logging towns. Figure 3 illustrates deforestation around the logging town of Pokola in Northern Congo.

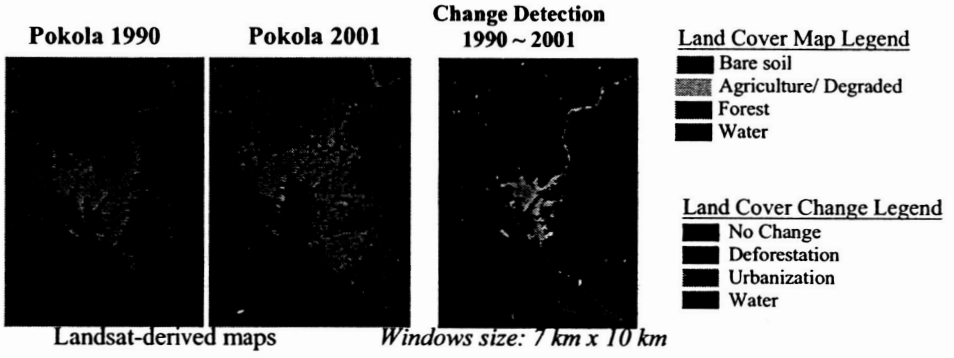

Figure 3. Mapping land cover change in logging town (Pokola).

References for results:

Laporte, N. T, T. S. Lin, J. LeMoigne, D. Devers, and M. Honzak. Toward an Integrated Forest Monitoring System for Central Africa. In: *Land Change Science: Observation, Monitoring, and Understanding Trajectories of Change on the Earth Surface*, Ed. G. Gutman. NASA-LCLUC Program, in press.

A-3. Mapping logging impact

Millions of hectares of forested land in the region are under concession (i.e., allocated for logging) – Figure 1. We have developed a simple "logging index" derived from Landsat satellite imagery. It allows estimating the number of trees harvested by forest unit (Figure 4). The development of such indicators is important because logging intensity is likely to intensify in the region (as more species are harvested per unit area). Furthermore, the more trees that are removed, the larger the impact on carbon sequestration and fluxes.

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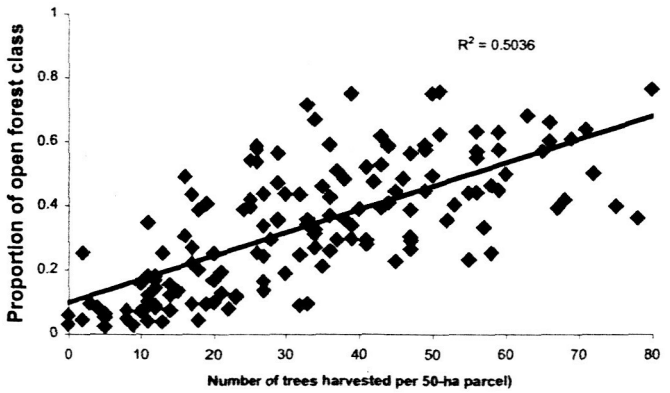

Figure 4: Developing a logging forest index for central Africa

References for results:

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Laporte N., 2003, Utilisation de la télédétection pour la gestion des ecosystème forestier du nord Congo- *Cas des UFA Kabo, Pokola et Loundoungou*, Rapport Technique au Wildlife Conservation Society, New York, USA.

B. Land cover mapping for forest conservation

Biodiversity conservation depends strongly on the management of both protected areas and their buffer zones. Unfortunately, in most of Central Africa, very little is known about the distribution of vegetation types and associated threats, such as deforestation, forest degradation, and forest fragmentation. While forest covers roughly 45% of Central Africa, only 10%, or 180,000 km^2, is currently protected.

The need for forest monitoring in Central Africa is urgent. National institutions in the region lack the most basic information to make land-use decisions and policy. Recent vegetation maps produced for the region were generated from low-resolution satellite imagery including AVHRR, SPOT vegetation and MODIS. These coarse-scale maps are useful for monitoring land cover at the regional level, but they are poorly adapted to forest conservation needs at the landscape level.

B-1. Mapping Habitat in Northern Congo

Wildlife management requires knowledge of habitat distribution and potential threats. Landsat TM imagery allows us to monitor forest cover around parks. A vegetation map of the Nouabalé Ndoki reserve(Northern Congo) was produced in collaboration with WCS researchers.

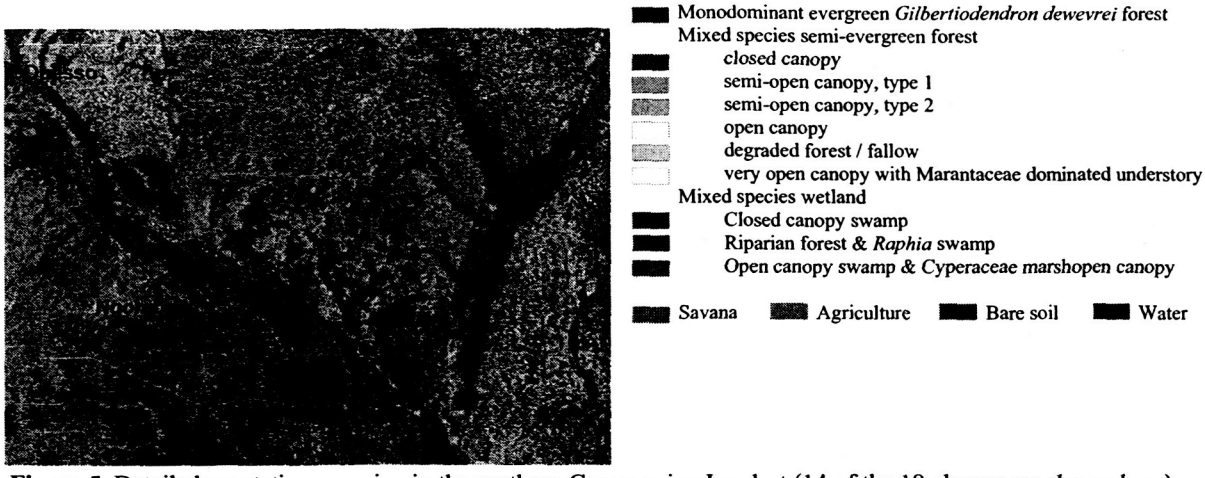

Figure 5. Detailed vegetation mapping in the northern Congo using Landsat (14 of the 18 classes are shown here)

References for results:

Laporte N., 2003. Utilisation de la télédétection pour la gestion des ecosystèmes forestiers du nord Congo- *Cas des UFA Kabo, Pokola et Loundoungou*, Rapport Technique au Wildlife Conservation Society, New York, USA.

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Lin, T.S., and N.T. Laporte. 2003. Using Aerial Videography to Validate Land Cover Map in the Tropical Rain Forest of Central Africa. Poster for American Geographic Union (AGU) 2003 Fall Meeting, 8-12 Dec., San Francisco.

B-2. Mapping forest habitat loss in the Albertine region

Because of the fragmented park system in south West Uganda and their lack of connecting corridors, the sustainability of viable wildlife populations is under severe threat. We found the Albertine forest in general to be fragmented, even in the Democratic Republic of Congo. In SW Uganda, dense forest can be found only in protected areas. To date rates of deforestation in this region have been poorly documented, and most deforestation occurs within a short distance from protected areas. The largest deforestated areas were located in the northern part of the protected area network, around Bugoma, Budonga, and Kagombe forests.

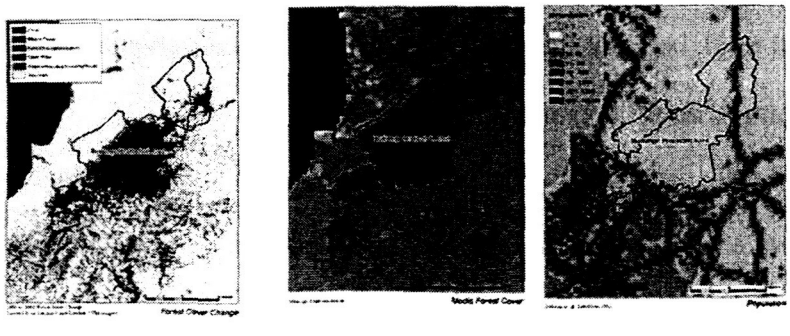

Figure 6a, b, c: Budongo Landsat TM deforestation map a) , MODIS tree cover b), and population density map c)

References for results:

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Laporte N., and T. Lin. 2003. Land Use Land Cover Change in the Albertine Region of Uganda. Paper Number: B42A-0943- American Geophysical Union-2003 Fall Meeting, 8-12 December 2003, San Francisco, California, USA.

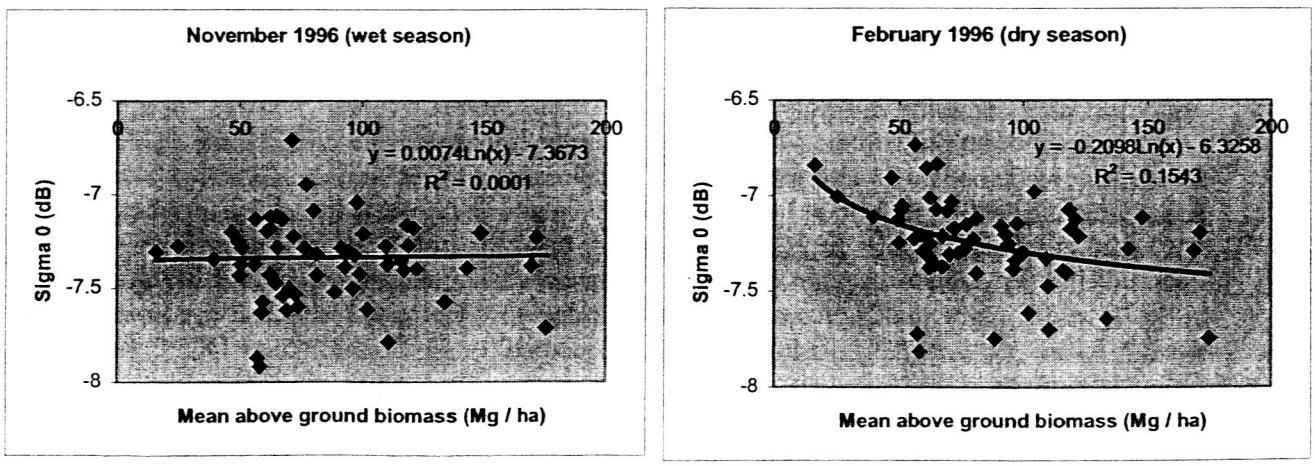
C. Data fusion & radar biomass estimates

C-1- Assessing biomass using radar imagery (JERS-1 100m mosaics)

We explored the utility of 100-m JERS-1 radar imagery for above-ground biomass estimation across a range of 1-ha plots in 61 study sites throughout southern Cameroon. Many studies have shown a positive correlation of radar backscatter to total above-ground biomass of different forests in the Northern Hemisphere. But tropical forests have a more complex structure and higher biomass than the northern forests, and it is expected that the assessment of south Cameroon forest biomass, using JERS-1 100 m mosaics provided by JPL, will be more challenging.

The field biomass measurements, collected in 1995 by Honzack (Co-I), were compared with the normalized backscatter of the 1996 JERS-1 mosaic produced by the NASA Jet Propulsion Laboratory (http://trfic.jpl.nasa.gov). We found poor relationships between the above-ground biomass measurements and backscatter for both low and high water mosaics. These findings suggest limited utility of JERS-1 radar imagery for biomass estimation across tropical Africa. Similar limitations have been noted in the Amazonian forests (Salas et al., 2002).

Figure 7a,b Mean above ground biomass v. JERS-1 Normalized backscatter (Sigma 0) in Cameroon



References for results:

Laporte, N. T, T. S. Lin, J. LeMoigne, D. Devers, and M. Honzak. 2004 Toward an Integrated Forest Monitoring System for Central Africa. In: *Land Change Science: Observation, Monitoring, and Understanding Trajectories of Change on the Earth Surface*, Ed. G. Gutman. NASA-LCLUC Program, in press.

C-2. Advance in Data integration/fusion -Fusion of SAR and optical data for vegetation mapping

A wavelet-based fusion method was developed for integrating high-frequency components of higher spatial resolution data (SAR data at 6m resolution) and low-frequency components of lower spatial resolution data (Landsat-TM at 30m resolution). The fusion provides a new image data set at 6m spatial resolution, which contains more detailed texture features used to improve land cover classification. At the same time, the fusion preserves the large homogeneous regions that are observed by the Thematic Mapper sensor.

References for results:

Le Moigne, J., N. Laporte, and N.S. Netanyahu. 2001. *Enhancement of tropical land cover mapping with wavelet-based fusion and unsupervised clustering of SAR and Landsat Image Data,* International Society for Optical Engineering (SPIE), Toulouse, 17-21 September 2001, Toulouse, France, 6p.

D- GOFC in central Africa – The OSFAC network

International efforts are underway to improve operational forest monitoring. At the first Central Africa "Global Observation of Forest Cover" workshop held in February 2000 in Libreville, Gabon, several issues limiting the development of operational forest monitoring systems were identified by national forest services and their international partners. These limitations included lack of technical and financial resources, poor access to data and information (including the Internet), and lack of training facilities and opportunities. It was also unanimously recognized that remote sensing is a key component to any forest monitoring system and that, at each stage of scientific understanding, there must be transfer of relevant information to policy and decision makers.

D-1. Outreach/ capacity building

In collaboration with the TREES project, we organized GOFC/CARPE regional forest monitoring workshops with international NGOs and national forest services. The first workshop took place in Libeville,Gabon, in the spring of 2000 and was followed by a more technical workshop in Lopé, Gabon in July 2000. The objective was to build a national capacity for operational forest monitoring. More than 30 in-country researchers participated in the workshop, which focused on practical applications of satellite data to forest monitoring and conservation. For 2003-2004, CARPE/USAID funds have been secured for the Central Africa GOFC Regional Office in Kinshasa (OSFAC).

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Laporte N. 2001. *Tropical deforestation in Central Africa, Briefing sheets #6*, Biodiversity Support Program, March 2001,Washington DC, 4p.
Laporte N. 2001. *Forest monitoring in Central Africa, Briefing sheets #13*, Biodiversity Support Program, March 2001, Washington DC, 6p.

D-2. Image Data Acquisition and distribution in Central Africa

Following the recommendation of the 200 GFC meeting, a series of Landsat TM, ETM+ and IKONOS images have been acquired through the NASA data purchase program and distributed to in-country CARPE and GOFC collaborators in order to implement local-scale land cover mapping activities. The remote sensing data acquired as part of this project and the NASA data buy have been distributed to our collaborators in the region. They are also freely available from GLCF and the OSFAC website (www.osfac.org). This regional network allows remote sensing information of this region to be shared. However, Internet access is still a limiting factor in central Africa in terms of speed and cost, and most of the data sets are still distributed via CD.

Conclusions & Issues

This NASA funded project has advanced knowledge of land-cover and land-use change in Central Africa and has promoted forest management and monitoring techniques using remote sensing. Capacity building in the use of remote sensing was built through organized workshops, scientific collaborations and data sharing with national forest services and conservation organizations, and through integration with the GOFC-OSFAC network. Nonetheless, Central Africa remains greatly understudied, partly due to diverse cultural and language differences and poorly developed infrastructure, but primarily due to the difficulty of working in such politically unstable countries. Since the mid-1990s, this "hot spot" of biological diversity and enormous carbon storage has undergone a series of devastating ethnic conflicts, which are to blame for the death of more than 3 million and the displacement of 2.7 million people. Partially because of this displacement, localized increases in forest loss are evident throughout the region, caused by agricultural expansion, charcoal production, and livestock grazing. Funding by NASA for this project has contributed significantly in improving forest management through the provision of low cost imagery, GIS data sets, and scientific results, but perhaps most importantly through capacity building and the promotion of international research collaborations. One notable social and cultural success of the study has been the creation of remote sensing/GIS units in each of our primary study sites, including at a large private logging company (CIB) interested in developing reduced impact logging techniques and achieving its timber certification.

Building upon these advances and coupling remote sensing science with specific information on ecosystems structure and function are the only ways to continue to track the rapid changes occurring in this vast forested region (> 1.8 million sq km), and to predict the impact of these changes on human populations, biodiversity, and carbon pools and fluxes. Little LANDSAT imagery after 2003 is available for the region, and MODIS does not provide the fine scale information needed for forest management by the logging companies, the national forest services, or the implementation of the forest monitoring system. Consequently, we recommend continued NASA support for the acquisition and processing of Landsat imagery of the regionin order to attainclear images for this extremely cloudy region.

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Results from our research have been focused on the development of an operational forest monitoring system in the region, and in this sense the project has been extremely successful. Results have been presented at numerous national and international conferences, distributed to in-country Forest Services, NGOs, and the collaborating timber products company. Some of the results have been published in scientific journals, and there will be further publications as we document and extend our research and applications in the region. We hope to continue to contribute to the NASA programs as part of the Land Cover/Land Use Change Science Team, and by advancing our research activities in the region through the NASA Carbon Cycle Science and related programs. We will also continue to pursue our remote sensing capacity building and forest monitoring activities in the region, where possible, under the GOFC-OSFAC and CARPE-USAID umbrella.

Acknowledgments

This research was supported by the NASA Land Cover Land Use Change Program and the Central Africa Regional Program for the Environment (CARPE). It would not have been possible without the logistic support of the Wildlife Conservation Society (Paul Elkan and Fiona Maisels) and the Congolaise Industrielle des Bois (Olivier Desmet, Dominique Paget). We want to thank the following individuals for generous donation of their time and their work dedicated to preserving these unique ecosystems: Steve Blake, Brian Curran, Bourges Djoni-Djimbi, Sarah Elkan, Mike Fay, Steve Gulick, Richard Malonga, Antoine Moukassa, and Chris Wilks. We also thank Yves Dubois, Leon Embon, Patrick Geffroy, Frederic Glannaz, Jackie Glannaz, Patrice Gouala, Christian Guyonvaro, Gregoire Kossa, Tom van Loon, Alfred Tira, and Luca van Der Walt for field assistance and working toward the sustainable use of the region's forest resources. I want also to thank my former research assitant at the University of Maryland, Didier Devers, for helping with the development of the OSFAC network and his technical assistance, and Debra Fischman and Jeremy Goetz for assisting in the mapping of logging roads.

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http://luci.umd.edu/lcluc/
(Before June 2004)